Available online www.jsaer.com

Journal of Scientific and Engineering Research, 2023, 10(5):261-270

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Comparison of the performance of CIGS and CdTe/CdS modules under real natural climatic conditions

P.W. Tavares[1,2], A. Ndecky[1,2], N. Mbengue[1], D. Gueye[2,3], B. Mbow[1], I. Youm[1]

[1]Laboratory of Semiconductors and Solar Energy (LASES) Department of Physics, Faculty of Science and Technology, Cheikh Anta Diop University of Dakar, Senegal
[2]Centre for Renewable Energy Studies and Research (CERER) BP 476 Dakar, Cheikh Anta Diop University, Dakar, Senegal
[3]Department of Physics, UFR SATIC, Alioune Diop University of Bambey, Bambey, Senegal
pierrewilliams.tavares@ucad.edu.sn

Abstract The objective of this article is to make a comparative study of the degradation of CIGS and CdTe/CdS thin-layer modules under real natural climatic conditions. To do this, we were able to compare two CIGS and CdTe photovoltaic modules by exposing them to real weather conditions for three months (January 4 to March 29, 2023). The measurements were made at the Centre for Renewable Energy Studies and Research (CERER). The CIGS module is not cleaned during the three months of study and is characterized by another CdTe/CdS-based thin layer module that was used to be compared to the CIGS. The CdTe/CdS is put under the same conditions as the CIGS module. During the 3 months of the study, for the CIGS module, losses are 4.68%, 55.22% and 60.22% for the open circuit voltage, short circuit current and maximum power respectively. The CdTe/CdS lost 60.01% power and 46.06% short circuit current.

Keywords solar module, thin film, current, voltage, power, performance, CIGS, CdTe/CdS, Senegal

1. Introduction

Renewable energies, mostly used a few centuries ago, were abandoned during the 20th century for practical and commercial reasons. With the depletion of fossil resources combined with the problem of global warming, renewable energies are experiencing a renewed interest. Renewable energies are very diverse but they all come from two sources: the sun and the earth.

These solar energy sources are made up of a number of technological sectors depending on the energy source. The field studied in this document is photovoltaic solar energy and this is provided by solar cells of different semiconductors. Silicon-based solar cells dominate the market with their satisfactory efficiency but their cost of manufacture, the weight of the panels and the problem of recycling the modules limit their development. Since then, in recent years, researchers have become increasingly interested in thin-film cells because of their fast and inexpensive manufacturing process. Among the candidates, the CIGS thin layer is considered to be one of the most promising absorbers to have very efficient yields, low production cost, excellent stability and high radiation resistance. But also, CdTe/CdS is widely used in thin film technology.

The objective of this work is to study the performance of a CIGS module and a CdTe/CdS module under real natural climatic conditions and to make a comparison between these two technologies.

Initially, the CIGS solar cell was a simple p-CuInSe/n-Cd/S heterojunction but the structure of the device was mainly configured to substrate formation/Mo/CIGS/CdS/ZnO/AZO/Al; the first CIGS solar cells were developed between 1976 and 1977 through two 100 MW/cm² tungsten halogen lighting modes for 1.2 cm² devices (p-CuInSe2/n-Cd/S) with a 4.5% efficiency by Karzmerski and Al at the University of Maine (USA) [1]. CIGS-based solar cells have excellent stability and resistance to solar radiation and have good low-light efficiency and higher yields (19.2%) [2]. CIGS modules have a typical/standard wavelength range of 350 to 1300 nm (higher than other solar cell technologies) and therefore have a higher spectral response in the infrared region of the light spectrum [3]. Most of the experimental results published in the field of CIGS cells show that the best yields are obtained with a gap of about 1,2 eV, which corresponds to a rate of 30% gallium and that the absorption coefficient of active layer CIGS decreases with the increase of the wavelength for this same rate of gallium [4]. Recently a research cell showed an efficiency of 23.35% with a surface of 1 cm² and without cadmium, making a non-toxic CIGS solar cell [5].

2. Climate actions on module parameters

The climatic parameters that influence the performance of the solar modules are generally lighting, temperature, humidity, wind speed, rainfall, ultraviolet (UV) radiation, dust and evaporation. Numerous studies published in the literature show that the performance of photovoltaic modules depends mainly on the technology, the site, the weather conditions and the configuration of the photovoltaic system [6].

2.1. Lighting

The energy produced by a panel depends on the illumination it receives on its surface. We know that the greater the amount of sunlight, the more efficient the module, so sunlight has a positive influence on the efficiency of the solar module because increasing the amount of sunlight leads to increased efficiency. The most important parameter in the photovoltaic conversion process is the illumination [7]. The current is generated by the solar module is essentially influenced by the intensity of the illumination, so the short circuit current is related to the illumination. Figure 1-15 below shows the I-V characteristic of a cell as a function of illumination; at a constant temperature and wind speed, it can be seen that the greater the illumination, the greater the short-current circuit is also important but the open circuit voltage decreases little.

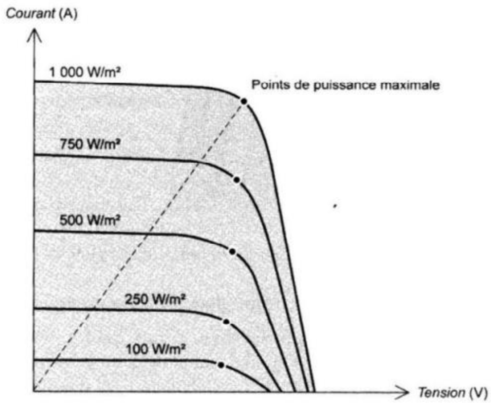

Figure 1: Influence of irradiation

2.2. Influence of humidity, wind, etc.

Beyond the temperature, the illumination and the deposition of dust on the solar modules, other parameters such as humidity, wind speed, etc. influence the performance of solar modules. The literature reports that humidity has two effects on the performance of a module. The first effect is the entry of moisture into the solar panel enclosure which leads to a decrease in its performance and the second is the effect of water vapour particles present in the atmosphere which can decrease the level of irradiance, this phenomenon decreases the reception level of the solar radiation component. Studies have shown that this effect on illumination results in a small variation in open circuit voltage and a large variation in short circuit current. High wind speeds are beneficial for the operation of PV modules. They decrease the operating temperature of solar cells [8]. The effect of cooling due to wind circulation should be included for a more accurate evaluation of the operating temperature of solar cells [9].

2.3 Site Layout

The measurements were carried out at the Renewable Energy Research and Study Centre (CERER) in real and natural operation, located in the DAKAR region more precisely on the route of the geographical service (HB-87) *rue HB-478, HANN BEL AIR. CERER is an institute of the Cheikh Anta Diop University of Dakar (UCAD) which was created by decree no. 80-402 of 28 April 1980.

This region has significant photovoltaic solar energy potential. The climate is of the Sudanese-Sahelian type characterized by the alternation of a dry season from November to May and a rainy season from June to October. Table 1 shows the meteorological data for the study area.

Table 1: Meteorological data

Months	Daily inclined solar radiation (kWh/m²/j)	Humidity (%)	Wind speed (m/s)	Ground temperature (°C)
January	5.54	70.2	5	21.7
February	6.32	74.9	4.9	21.7
March	6.8	78.5	5.4	22.3
April	6.77	83	5.6	23
May	6.3	82.9	5.1	24.8
June	5.74	82.3	4.2	27.4
July	5.25	79.7	3.9	28.3
August	5.16	83	3.7	28.2
September	5.38	84.7	3.4	28.1
October	5.89	81.8	3.9	28.1
November	5.57	73.8	4.6	26.5
December	5.22	68.6	5.2	23.9

3. Materials Used

3.1 The CIGS solar module

Measurements were made on two (2) thin film photovoltaic modules:

- 1 CIGS (Copper, Indium, Gallium and Selenium Cell) module with 90 W peak power, rectangular (960*640) flexible Solar Panel and produced in China.
- 1 module of CX3 75, thin-film, 75 W peak power CdTe/CdS-based, 1200*600 rectangular and produced in Germany.

The electrical characteristics of these different photovoltaic modules are given in STC (Standard test conditions) namely the solar radiation which is 1000 W/m²; the temperature is 25°C and the air mass is AM = 1.5 and are listed in Table 2.

3.2. The test protocols

In this study, we study the performance of CIGS-based thin-film solar modules exposed under real natural climatic conditions. These modules are positioned in the south and an inclination of 15° relative to the horizontal meaning the latitude of the place.

Both modules are exposed to the open air in the same weather conditions, the characteristics of the CIGS and CdTe/CdS modules are noted just before the experiment and at the end of the experiment. The study is carried out over a period of 3 months (12 weeks).

Before the start of the experiment, the characteristics of the solar modules such as the open circuit voltage, short circuit current, illumination and temperature of the modules were recorded. Various experimental results are obtained from current-voltage and power-voltage measurements according to environmental conditions, namely temperature, illumination, dust deposition etc. For each measurement, almost 50 values are recorded to trace the current-voltage characteristics. Measurements were made during the dry season (January 4 to March 29) between 1200 and 1300.

The aim is to compare the performance of the two modules. We look at the drop in performance of the CIGS module and the CdTe/CdS module to see the evolution of the drop in performance and compare them.

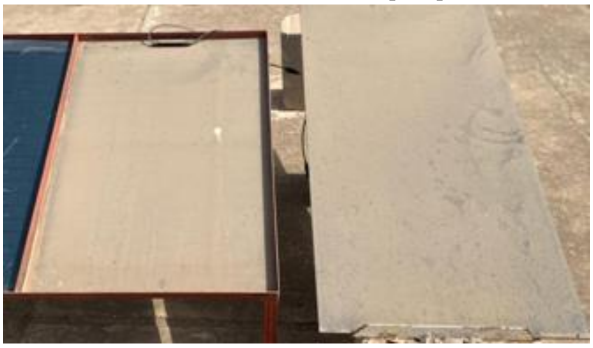

Figure 2: Test platform (CIGS on the left and CdTe/CdS on the right)

3.3. Measuring equipment

We used a CIGS module, a CdTe/CdS module, two multimeters to measure voltage and current, rheostats to play the role of the load, a Solarimeter model DT 1307 to measure the illumination and a thermometer with thermocouples type K/J to measure the temperature of the photovoltaic panel. To trace the current-voltage characteristic, the data put in Excel are imported into the MATLAB software where we have written programming that allows us to trace the curves.

For multimeters: two have been used, one acting as an ammeter and the other as a voltmeter. The model used is a CAT IV HT64 digital multimeter with TRMS measurement. It measures electrical current, voltage and resistance over different measurement ranges:

Continuous voltage (DC) and alternating voltage (AC); Diode test; Resistance measurement and continuity test;

Table 3: Multimeter DC Voltage Specifications

Scale	Resolution	Uncertainty	Impedance	Overvoltage's protection
600 Mv	0.1 mV	+/-(1% read + 4 dgts)	>10 MΩ	1000 V DC/AC
6000 V	1 V			
60 V	0.01 V			
600 V	0.1 V			
1000 V	1V			

Table 4: Multimeter DC Current Specifications

Scale	Resolution	Uncertainty	Overvoltage's protection
600 µA	0.1 µA	+/-(1% read + 3 dgts)	Fusible 800 Ma/1000 V
6000 µA	1 µA		
60 mA	0.01 Ma		
600 mA	0.1 Ma		
6000 A	0.001 A	+/-(1.5 read +3 dgts)	Fusible 10 A/1000 V
10 A	0.01 A		

Figure 3: Digital multimeter

For thermometer with thermocouple: we used type K/J LCD display (4 digits) double input with a width of 55 mm: for use with thermocouple K and J, temperature display in °C, ° F or Kelvin, double measurement, double display, minimum and maximum measurement, display freeze function, AVG function of the last 10 measurements, automatic shutdown.

Figure 4: Thermometer with thermocouple

For the Solarimeter: a model DT 1307 Solarimeter was used to measure the irradiation.

Figure 5: Solarimeter

For rheostat: three rheostats connected in series were used to play the load roles. The coiled variable resistors are used as means of adjustment of current or alternating voltage (AC) and continuous voltage (DC). Each rheostat has a nominal resistance of 3.3 Ω, the tolerance of resistance is 10%, the permissible permanent load at room temperature is 23°C (10 A), the insulation resistance is greater than 3.10 Ω, the grounding resistance is less than 0.1 Ω, the permissible voltage on the terminals is 600 V maximum, the breaking voltage against the case is greater than 2500 V, the degree of protection is IP 20 and the construction is according to EN 61010-1.

Figure 6: Rheostat

4. Results and Discussion

4.1 Presentation of results

The variation in electrical characteristics over three months under actual natural climatic conditions is presented in Table 5:

Table 5: Characteristics of the two modules

CdTe/CdS module measure	Vco (V)	Icc (A)	Pm (W)	η (%)	FF (%)
Initials measure	37.91	1.98	61.65	9.43	81.97
Finals measure	25.65	1.068	24.65	3.8	89.99
CIGS module measure	Vco (V)	Icc (A)	Pm (W)	η (%)	FF (%)
Initials measure	23.68	4.27	72.22	12.55	71.39
Finals measure	23.87	2.647	28.69	6.53	60.33

The fill factor FF is obtained from the equation [5]:

$FF = (V_{max} * I_{max})/(V_{co} * I_{cc})$

the yield is given by the equation [6]:

$\eta = (V_{max} * I_{max})/(\phi * S)$

ϕ (W/m²): incident light power

S (m²): surface of the module

The current-voltage and power-voltage characteristics of the two GICS and CdTe/CdS modules studied during the three months of exposure to natural and actual climatic conditions are presented below:

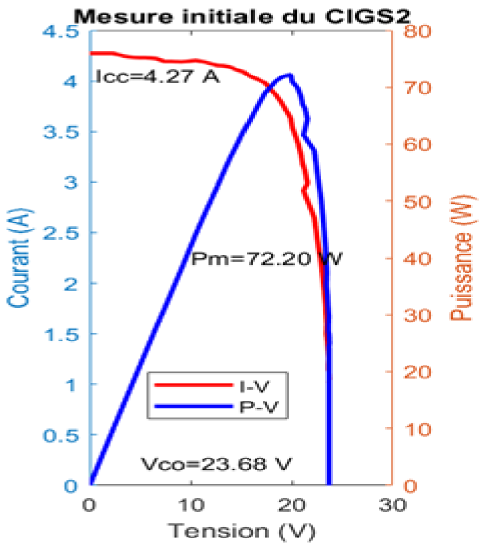

Figure 7: Initials measure of CIGS module

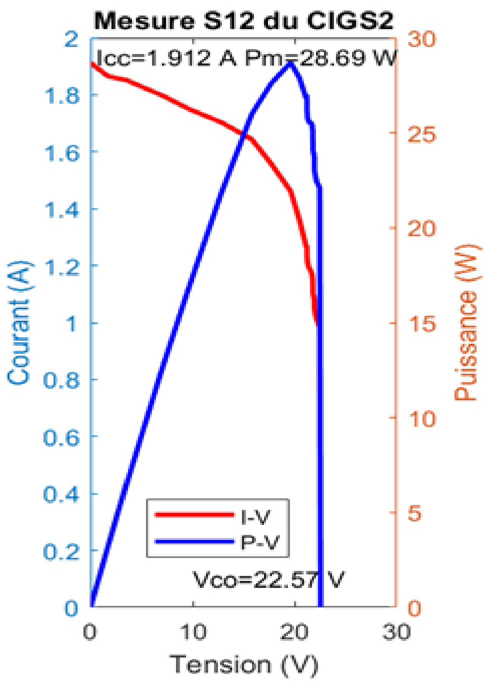

Figure 8: Finals measure (after 12 weeks) of CIGS module

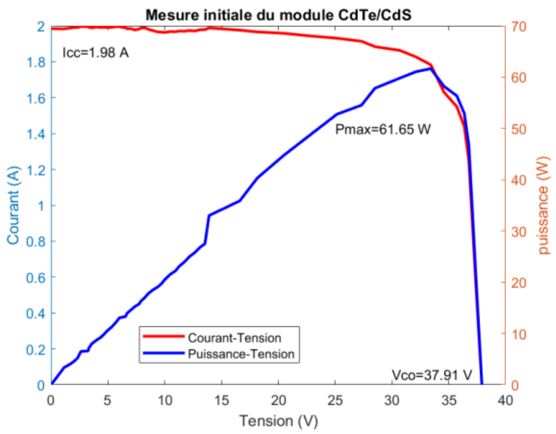

Figure 9: Initials measure of CdTe/CdS module

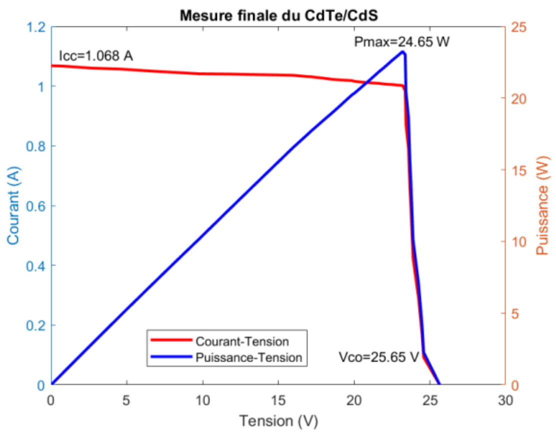

Figure 10: Finals measure (after 12 weeks) of CdTe/CdS module

The figures above represent the current-voltage (I-V) and power-voltage (P-V) characteristics of the two CIGS and CdTe/CdS thin film technology modules. They are left to the accumulation of dust particles during three months of exposure to natural and real weather conditions.

Both modules were initially characterized.

For CIGS, the open circuit voltage is 23.68 V, the short circuit current is 4.27 A, the maximum power is 72.22 W, the efficiency is 12.55% and the form factor is 71.39%.

For CdTe/CdS, the open circuit voltage is 37.91 V, the short circuit current is 1.98 A, the maximum power is 61.65 W, the efficiency is 9.43% and the form factor is 81.97%.

4.2 Comparison between the two modules

The following table shows the variations in the electrical characteristics of the CIGS module and the CdTe/CdS during the three months of exposure without cleaning.

Table 6: Variation of electrical parameters of CIGS and CdTe/CdS modules

Modules	Characteristics	Absolute values	Relative values
CIGS	Voc	-1.11	-4.68%
	Icc	-2.358	-55.22%
	Pmax	-43.53	-60.27%
	ɳ	-7.21	-57.45%
	FF	-4.89	-6.84%
CdTe/CdS	Voc	-12.26	-32.33%
	Icc	-0.912	-46.06%
	Pmax	-37	-60.01%
	ɳ	-5.63	-59.7%
	FF	8.02	9.786%

4.3. Discussion

Figures 7, 8, 9 and 10 show the current-voltage (I-V) and power-voltage (P-V) characteristics. These characteristics show the masking effect caused by dust deposition the surface of the modules throughout the exposure. Indeed, the dust induces generally non-uniform shading on the surface of solar modules, so the chains of photovoltaic cells no longer receive the same amount of sunlight intensity, this is due to the decrease in the maximum power and this decrease in power is due to a decrease in the intensity of the nominal current. Thus, the short circuit current and power decrease in proportion to the rate of dust accumulation on the module surface. The variation of some parameters is due to the fact that the test modules were characterized by different sunshine and temperatures. This maximum power drop is accompanied by the drop of other electrical characteristics such as short circuit current, open circuit voltage, conversion efficiency and form factor. Thus, at the from the accumulation of dust particles on the surfaces of the modules, it can be said that the variation of the illumination is at the origin of the variations of the short-circuit current and the maximum power. Thus, the decrease in illumination negatively affects the electrical characteristics of the module more particularly the maximum power and short circuit current. So, the increase in radiation causes an increase in module efficiency.

The variation of the open circuit voltage is due to the variation of the temperature, so the increase in temperature negatively affects the open circuit voltage of the solar modules. The module is sensitive to temperature rise.

The results obtained in Table 6 allow us to compare the two thin film modules as, the degradation of the maximum power is very important for the two modules, it is in the order of -60% (ie -60.27% for the CIGS and -60.01% for the CdTe/CdS). But for the short circuit current, the loss is greater in the CIGS module than in the CdTe/CdS with relative values of -55.22% and -46.06% respectively. At the open circuit voltage (Voc), we have a degradation of -32.33% for the CdTe/CdS compared to -4.68% for the CIGS. There is also a significant loss in the yields of the two thin layer modules with a variation of less than 60% (that is -57.45% for the CIGS 2 module and -59.70% for the CdTe/CdS module). The form factor also showed a variation of -6.84% for the CIGS, but as for the CdTe/CdS, there is an increase of 9.786%.

When talking about the performance of a photovoltaic module, the most important parameter is the maximum power (Pmax) and that for our study the drop in the maximum power of the two compared models is the same, these two modules have the same degree of resistance to real natural climatic conditions.

As the characterization of two modules was made at different sunshine and the determination of maximum power is complicated because it is a function of total and spectral irradiation (which varies continuously because of the effect of the Earth's atmosphere), the spatial and temporal uniformity of the irradiation of the temperature of the module, the study does not allow us to know precisely which module is more efficient under natural conditions without cleaning.

5. Conclusion

The impact of meteorological parameters on the evolution of the electrical characteristics of thin-film photovoltaic modules is demonstrated by an experimental study that lasted three months. To do this, we compared a solar module based on CIGS exposed to real natural climatic conditions for three months to see the power evolution with another thin layer module based on dusty CdTe/CdS to track the degradation of their power.

We found that during the three months of exposure to natural conditions without cleaning, the CIGS module lost an average of 20.74% of its maximum power. And for the comparison of the CIGS module to the CdTe/CdS module, both have the same power loss with -60.27% for the CIGS and -60.01% for the CdTe/CdS. The comparison of these results shows that, like other technologies, environmental parameters such as dust deposition too influences the electrical parameters of a thin-layer solar module based on CIGS and CdTe/CdS.

In perspective, we plan to extend the study over 12 months to better see the evolution of the power of these modules under real natural conditions for all seasons of the year.

References

[1]. Erteza Tawsif and Md Meganur Rhaman and Al. A review of primary technologies of thin-film solar cells; Engineering Research Express, 2021, https://doi.org/10.1088/2631-8695/ac2353.

[2]. Mostefaoui, M et Mazari, H et Khelifi, S et Bouraiou, A et Dabou. Simulation de cellules solaires CIGS à haut rendement avec le logiciel SCAPS-1D ; 2015, energy process.

[3]. Isabelle CB, Ricardo A, Marques Lamciriuhas et Carlos AF Fernandes, Etude comparatives de la cellule solaire cuivre indium gallium séléniure (CIGS) avec d'autres technologies solaires, 2021, 7 Mars.

[4]. Charles Roger. Développement de cellules photovoltaïques à base de CIGS sur substrats métalliques, thèse pour obtenir le grade de docteur de l'université de Grenoble, Submitted on 25 Mars 2014.

[5]. M. Nakamura, K. Yamaguchi, Y. Kimoto, Y. Yasaki, T. Kato and H. Sugimoto, "Cd-Free Cu (In, Ga) (Se, S) 2 Thin-Film Solar Cell with Record Efficiency of 23.35%", IEEE Journal of Photovoltaics, vol. 9, pp. 1863-1867, (2019).

[6]. G. Mohand Kaci, A. Mahrane, M. Chikh, et A. Oulebsir, Etude comparative des performances de modules photovoltaïques de différentes technologies dans un climat méditerranéen. J. Ren, énergies, volume 17 non 2, page 291-300, Juin

[7]. Van dyk et al, Mnotiring current- voltage characteristics and energy output of silicon photovoltaic modules. Renewable Energy, 30(3): 399-411. 2005.

[8]. Xydis et al, The wind chill temperature effect on a large-scale PV plan exergy approach. Progress in photovoltaics: Research and applications, 21(8): 1611-1624, 2013.

[9]. Schwingshackl et al, Wind effect on PV module temperature: Analysis of different techniques for an accurate estimation. Energy procedia, 40: 77-86, 2013.

[10]. El Hadji Abdoulaye Niass et al., "Study of the Impact of Dust on the Electrical Performance Parameters of CIGS Modules Installed in a Sahelian Environment", Elixir Materials Science 55717 159 (2021) 55717-55720.

[11]. Hawa Diatara Ndiath et al., "Degradation Assessment of a Photovoltaic Plant After Several Years of Operation", Science Journal of Energy Engineering. Vol. 6, No. 1, 2018, pp. 1-7. doi: 10.11648/j.sjee.20180601.11